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Title: Verification Study of Metal Additive Manufactured Stretch-Dominated Lattices

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Verification Study of Metal Additive Manufactured Stretch-Dominated Lattices

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April 10, 2019

Outline

Stretch-Dominated & MAM

Beam Member Modeling

Continuum Element Modeling

Beam & Continuum Comparison

3-Point Beam Bending

Stretch-Dominated & MAM

Beam Member Modeling

Continuum Element Modeling

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3-Point Beam Bending

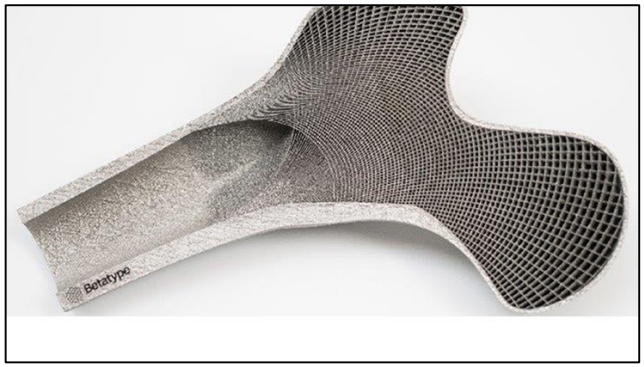
Areas of Impact

- Medical
- Safety
- Aerospace
- Sport, and etc.

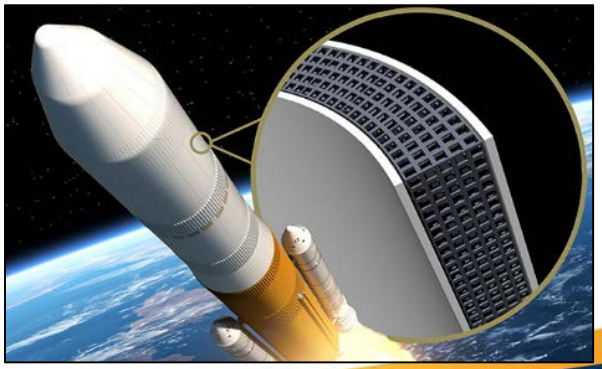
(Engadget, 2019)

(TCT Mag, 2017)

(3DMPMAG, 2017)



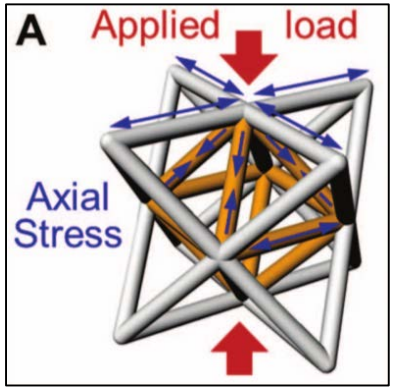
(TMD, 2018)



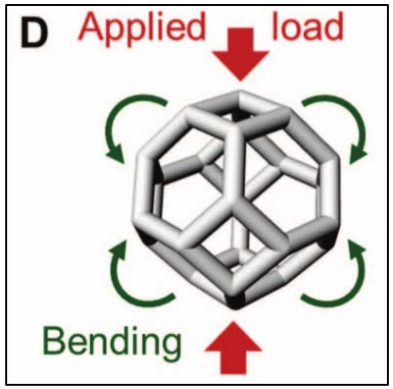
(ETHZ, 2016)

Cellular Structures

- Ordered structures are lattices while randomly ordered structures are foams.
- Two classes of lattice structures
  - **Stretch dominated**
  - **Bend dominated**



Stretch Dominated
(X. Zheng et al, 2014)

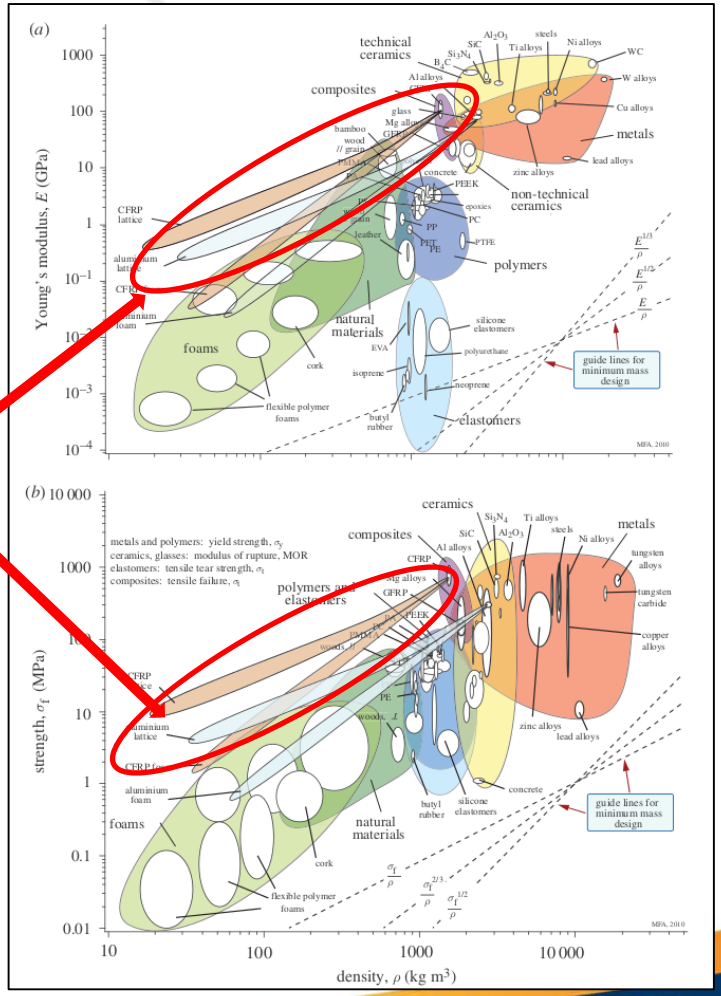


Bend Dominated
(X. Zheng et al, 2014)

Stretch Dominated Properties

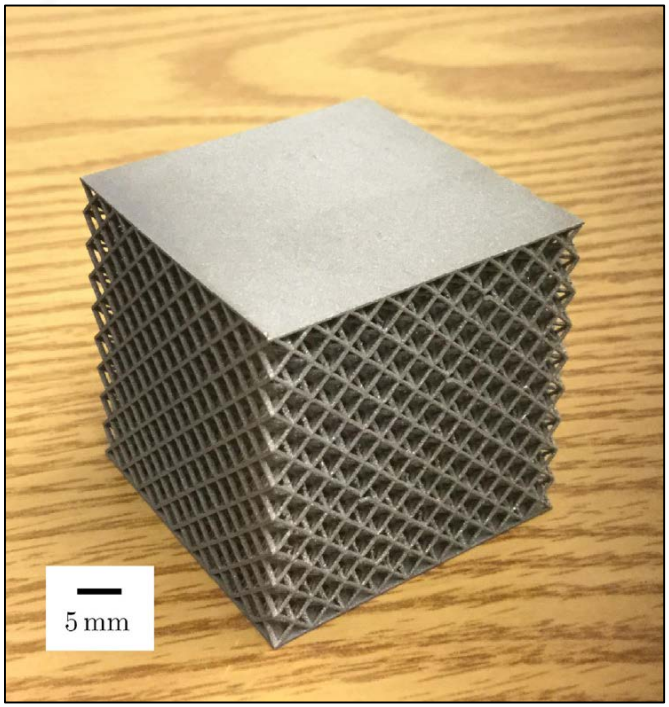
- Young's Modulus and yield strength scale linearly with relative density
- Principal Deformation in axial direction (struts)
- Higher yield strength than bend dominated

Cellular Structures



(N. Fleck et al, 2014)

Metal Additive Manufacturing



(M. Messner et al, 2015)

- Development has enabled accurate construction of complex 3D structures.
- Control of micro-geometries means properties can be designed based on structure.

Stretch-Dominated & MAM

Beam Member Modeling

Continuum Element Modeling

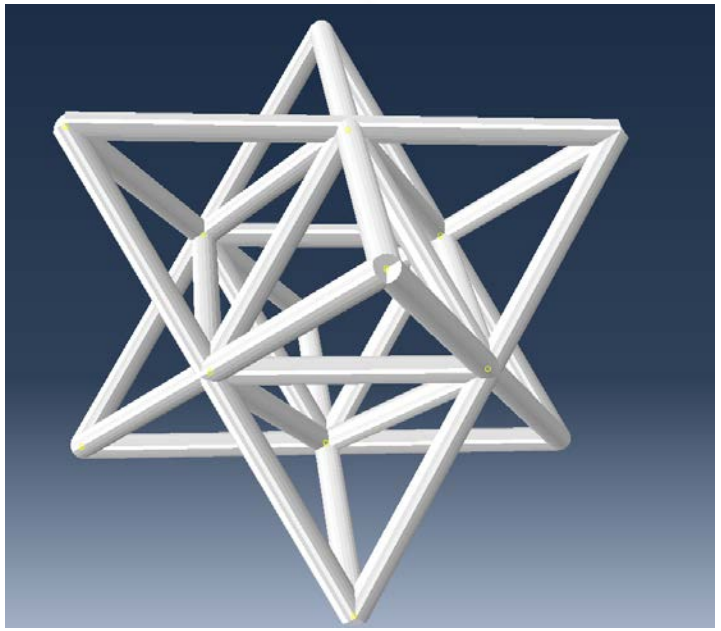
Beam & Continuum Comparison

3-Point Beam Bending

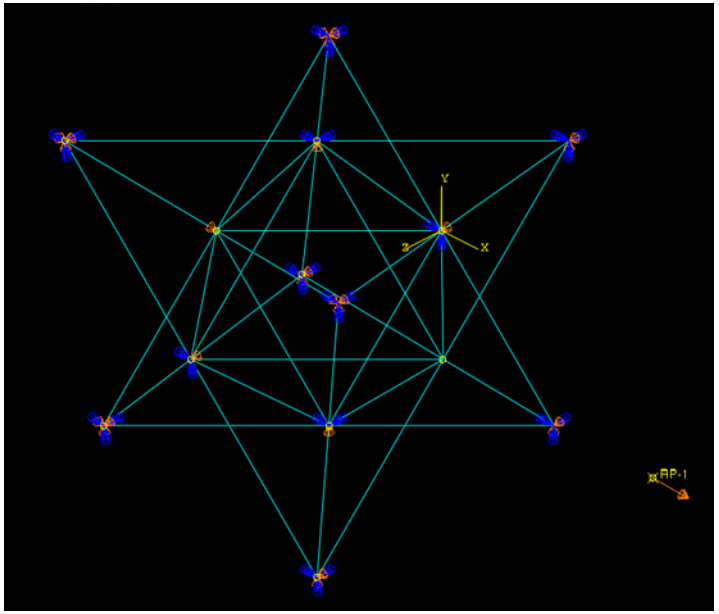
Beam Element Modeling

- Recreated literature model using beam element in Abaqus
- Octet design conditions:
  - Relative density ($\bar{\rho}$) = 10%
  - Strut length (l) = 3 mm

$$\bar{\rho} = 6\sqrt{2}\pi\left(\frac{a}{l}\right)^2$$



Beam Element Characteristics

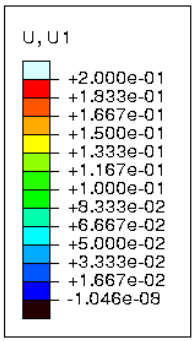


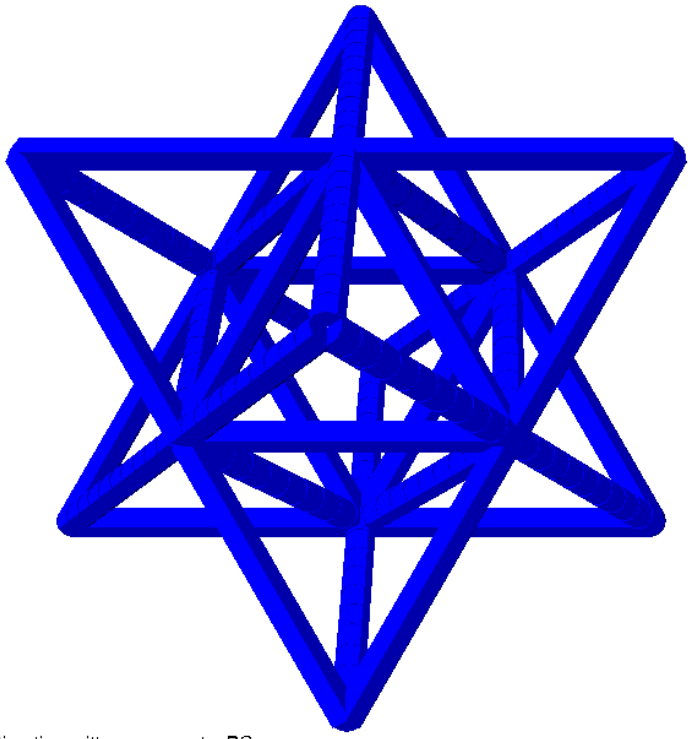
- Material Properties:

Density (tonnes/mm^3)	1.13e-9
Elastic Modulus (MPa)	1780
Poisson Ratio	0.35
Yield Stress (MPa)	40
Plastic Strain	0

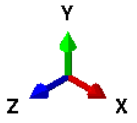
- Boundary conditions
  - Displacement in x-direction
  - Symmetry boundary in y- and z-directions

Beam Element ODB Video





Max Displacement = 0.2 mm



Displacement in the +X-direction with no symmetry BC
ODB: X_DISP_NoSymBC.odb Abaqus/Standard 3DEXPERIENCE R2018x HotFix 3 Fri Feb 08 16:14:54 MST 2019

Step: Displacement, Displacement in +X-direction
Increment 0: Step Time = 0.000
Primary Var: U, U1
Deformed Var: U Deformation Scale Factor: +4.550e+00

Stretch-Dominated & MAM

Beam Member Modeling

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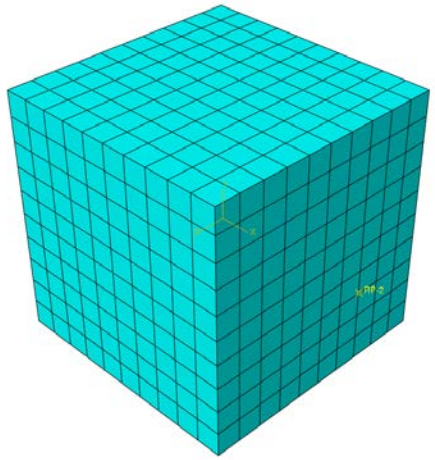
Continuum Element Modeling

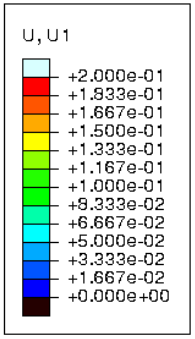
- Use of representative volume elements for unit cell (UC) would decrease total elements
- Same BC's and material properties except for stiffness
  - Set as orthotropic for linear elastic response

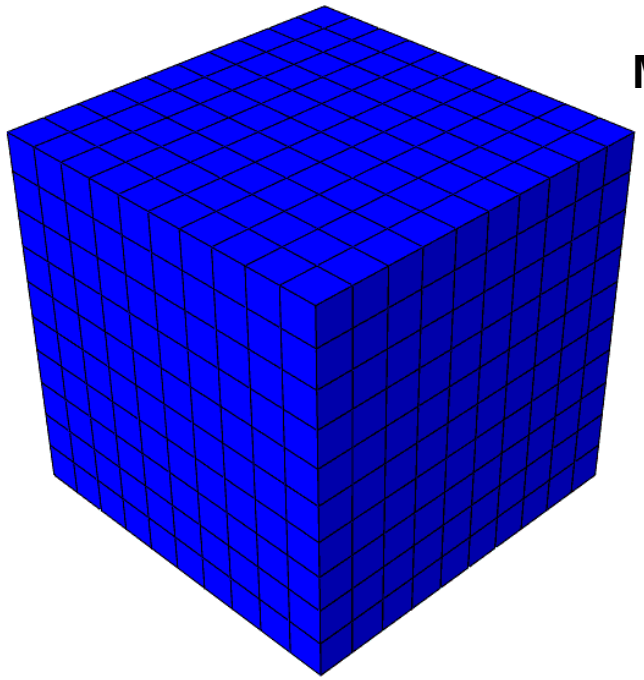


$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{13} \\ \sigma_{12} \end{bmatrix} = E\bar{\rho} \begin{bmatrix} \frac{1}{6} & \frac{1}{12} & \frac{1}{12} & 0 & 0 & 0 \\ \frac{1}{12} & \frac{1}{6} & \frac{1}{12} & 0 & 0 & 0 \\ \frac{1}{12} & \frac{1}{12} & \frac{1}{6} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{12} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{12} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{12} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ 2\varepsilon_{23} \\ 2\varepsilon_{13} \\ 2\varepsilon_{12} \end{bmatrix}$$

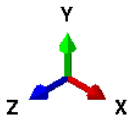
(M. Messner et al, 2015)

Continuum Element ODB Video





Max Displacement = 0.2 mm



0.2 mm Displacement in the positive x-direction for small cube
ODB: SmallCube_Point2mm_DISP.odb Abaqus/Standard 3DEXPERIENCE R2018x HotFix 3 Wed Mar 20 14:06:52 MDT 2019

Step: Displacement, Displacement in the +x-direction
Increment 0: Step Time = 0.000
Primary Var: U, U1
Deformed Var: U Deformation Scale Factor: +3.000e+00

Stretch-Dominated & MAM

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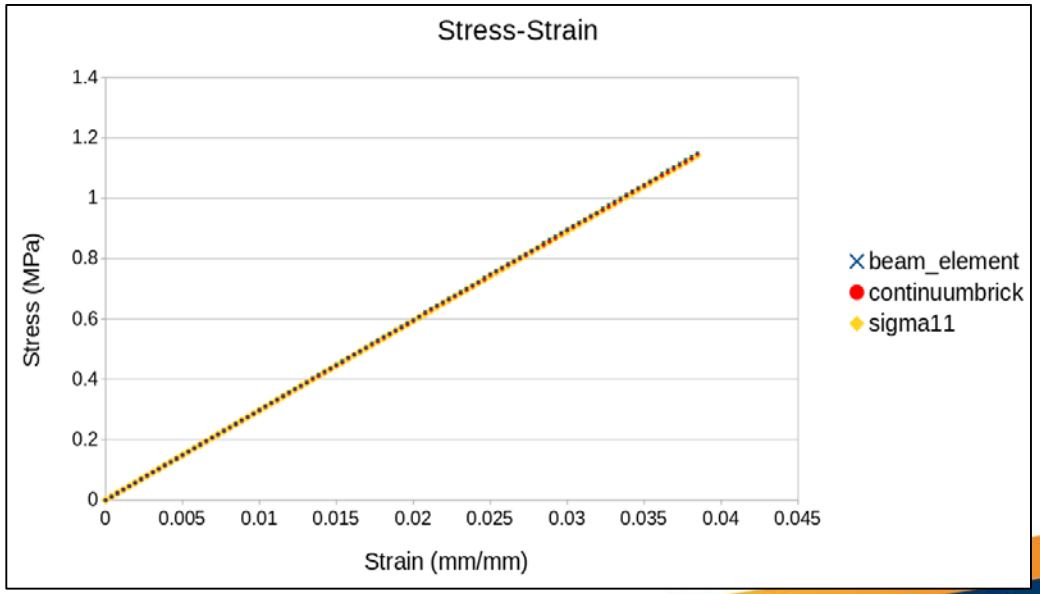
Comparing Models

- Used reaction force and displacement of reference point for stress-strain curve
- From stiffness matrix, derived analytical solution for stress-strain relationship

$$\sigma_{11} = \frac{E * \bar{\rho} * \epsilon_{11}}{6}$$



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Stretch-Dominated & MAM

Beam Member Modeling

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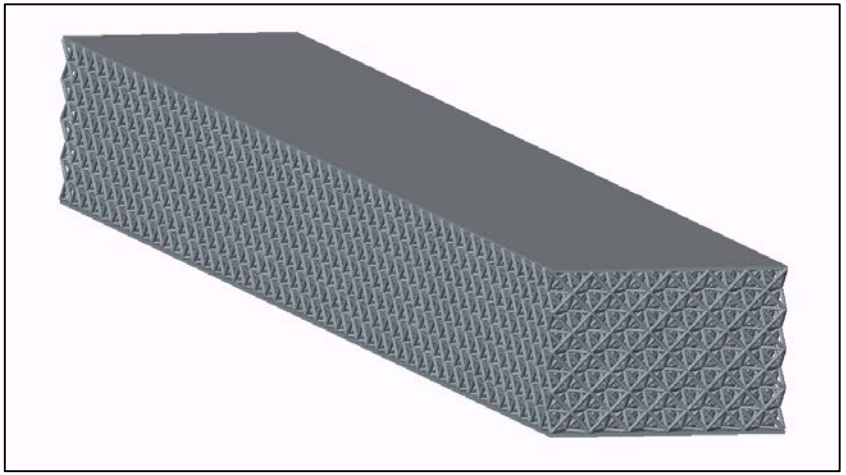
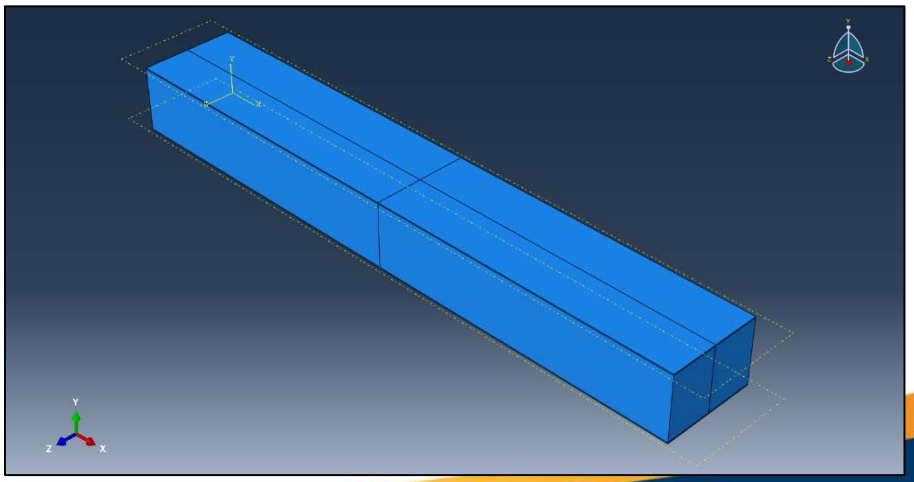
3 Point Bending Test

- Compare model to test data
- Beam consists of octet lattice with face plates
  - Length=47 UC (~200 mm), Width= 6 UC (~25 mm), Height=4 UC (~17 mm)
  - 1128 Unit Cells
- Model with representative volume elements





Future Work

- Perform mesh verification study
- Determine bending beam analysis criteria
- Look into other stretch dominated and bend dominated structures
- Compare lattice structures to topology optimization structures.

References

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Questions?